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Annual Report for Period: 08/2003 - 08/2004
Principal Investigator: Chapman, Michael S.
Organization: GA Tech Res Corp - GIT
Title:
ITR: Cavity QED with Trapped Ions

Submitted on: 07/07/2004
Award ID: 0326315

Project Participants

Senior Personnel

Name: Chapman, Michael
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: You, Li
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Monroe, Christopher
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Blinov, Boris
Worked for more than 160 Hours: Yes
Contribution to Project:

Graduate Student

Name: Moehring, David
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Madsen, Martin
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Deslauriers, Louis
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Sauer, Jacob
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Fortier, Kevin
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Brown, Nathaniel

Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Steele, Adam
Worked for more than 160 Hours: No
Contribution to Project:

Undergraduate Student

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

UNIVERSITY OF MICHIGAN

Other Collaborators or Contacts

Prof. Luming Duan, (University of Michigan, Dept. of Physics

Activities and Findings

Research and Education Activities:

The focus of the project is to develop a scalable trapped ion + cavity system capable of storing, manipulating, and transmitting quantum information over large distances. The significant technical hurdles challenging the objectives of this work are being systematically addressed, and the state-of-the-art in critical underlying technologies are being advanced through a close collaboration with key industrial companies and fabrication facilities. A theoretical component is exploring coupling strategies between atomic and photonic qubits, while supporting the experimental program with realistic models of actual devices.

The trapped ion + cavity system has the potential for being the future's most attractive architecture for quantum information processing. Atomic ions will form the backbone of tomorrow's most advanced atomic clocks, and are equally well suited for tomorrow's qubit memories. Virtually all protocols for communication of quantum information call for photonic qubits that are only weakly influenced by the environment. Coupling these two vital systems may provide the path toward large-scale distributed quantum computation, entanglement-sharing, and fault-tolerant quantum error-correction for faithful transmission of quantum information over remote distances.

Activities at Michigan have concentrated on the ion trapping portion of the project, with two main thrusts. One activity has arisen in Fall, 2003, representing an opportunity to entangle a single trapped ion with a single photon. This new approach in coupling atomic and photonic qubits does not rely on surrounding the ion with an optical cavity, but will ultimately require cavities in order to increase the speed of this coupling and its usefulness for quantum information applciations such as quantum repeaters and photonic scaling of trapped ion quantum computers. The second activity is the design and fabrication of an open ion trap electrode structure that will allow the trap size to be varied and allow the placement of nearby dielectric mirrors for future cavity-QED experiments. En route, this novel trap structure may support the strongest atom trap ever demonstrated, and allow ion trap electrodes to be within 10-20 micrometers from the ion.

Activities at Georgia Tech have focused on the development of high finesse cavities for the Ba+ transition as well as the development of the laser systems necessary to laser cool the ion and excite the ion cavity system. We anticipate that these systems will be complete and ready for the first stage of integration by the end of the summer.

In addition to our experimental work and published papers, we have also presented our work at international meetings.

co-PI Monroe:
ò Fields Institute Workshop of Quantum Information (Toronto, CA), Jul-04
ò FOCUS Workshop on Coherent Control Comp. Devices (Ann Arbor, MI), Jun-04
ò FOCUS/MCTP Workshop of Trapped Ion Quantum Computing (Ann Arbor, MI), May-04
ò APS Division of AMO Physics annual meeting (Tucson, AZ), May-04
ò Harvard-Smithsonian ITAMP Mesoscopic Physics Workshop (Cambridge, MA), May-04
ò NIST Quantum Information Science and Emerging Technologies (Boulder, CO), Apr-04
ò QUEST European Network on Atoms/Ions as Qubits (Torino, Italy), Mar-04
ò European Union Focus Meeting on Few-Qubit Applications (Budmerice, Slovakia), Dec-03

co-PI You:
ò Workshop on quantum computing and quantum information, Capital Normal University, Nov. 7-8, 2003.
ò Midterm review workshop of the major project in theoretical physics of the CNSF, Feb. 25th, 2004, Beijing.
ò The Conference on Frontiers of Quantum Gases, May 10-14, ITP, UCSB, 2004.

PI Chapman:

ò Frontiers in Optics, Optical Society of America Annual Meeting, Tucson, AZ, October 2003.
ò Elementary Quantum Processors, 304th W.E Heraeus Seminar, Bonn, Germany, October 2003
ò Southeastern Section of the APS Annual Meeting, Wrightsville, NC, November 2003
ò Conference on Frontiers of Quantum Gases, KITP, U.C. Santa Barbara, May 2004
ò FOCUS/MCTP Workshop of Trapped Ion Quantum Computing (Ann Arbor, MI), May-04

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:
During the 2003-2004 academic year, the researchers on this project consisted of 1 postdoc, 7 graduate students, and 1 undergraduate student located at two different institutions. In addition to local group meetings, these team gather for weekly meetings, where results are disseminated and both short-run and long-run plans are outlined. We continue to foster the development of undergraduates in laser physics, quantum information science, and general AMO research, as we have gotten two U. Michigan juniors deeply involved in the research activities in this project as well as the overall group activities.

Each of the students (including undergraduates) has been given the opportunity to travel to meetings, workshops, and schools where they have presented their research to the broader community (both oral papers and poster presentations). Below is a list of presentations offered by students and postdocs specifically related to this project.

ò Jul-04, Fields Institute Conference on Quantum Information Science, Toronto, CA (L. Deslauriers, contributed talk)
ò Jun-04, 4th Canadian Summer School on Quantum Information Science, University of Waterloo, Ont, Canada (D. Moehring, L. Deslauriers, posters)
ò May-04, Trapped Ion Quantum Computing, University of Michigan (B. Blinov, M. Madsen, D. Moehring, L. Deslauriers, posters)
ò May-04, IQEC, San Francisco, CA, (D. Moehring, postdeadline talk)
ò May-04, DAMOP, Tucson, AZ, inv. Talk (B. Blinov, invited talk; M. Madsen, contributed talk, K. Fortier, contributed talk)
ò Aug-03, Quantum Enabled Science and Technology (QUEST), Los Alamos, NM, (B. Blinov, invited talk)

Outreach Activities:
The Michigan Ion Trap laboratory has become a perennial attraction for many visitors, including several High School groups touring the campus and the Department of Physics. The ability to see individual atoms on a TV camera in real time is something that even younger students seem to appreciate. As part of our outreach activities, PI Monroe has traveled to several universities and organizations, including undergraduate institutions, to speak generally about scientific research and specifically about quantum mechanics and its modern laboratory applications. In addition to these engagements, Monroe continues service to the American Physical Society Division of Laser Science as a Distinguished Traveling Lecturer. In the period 8/2003 û 8/2004, PI Monroe has given the following educational presentations and lectures:

ò Colloquium, 'Atom entangled with photon: the best of both quantum worlds,' University of Michigan (Ann Arbor, MI), Apr-04
ò Colloquium, 'Entanglement between a single atom and photon,' University of Illinois (Champaign, IL), Nov-03
ò Colloquium, 'Quantum Computing with Individual Atoms,' University of Buffalo (Buffalo, NY), Nov-03

ò Undergraduate Lecture, 'Quantum Computing and Schrodinger's Cat,' St. Cloud State University (St. Cloud, MN), Oct-03
ò Lecture Series, Neils Bohr Institute, Quantum Optics Summer School (Copenhagen, Denmark), Aug-04
ò Lecture Series, 4th Canadian Summer School on Quantum Information Science, University of Waterloo (Waterloo, Ont, Canada), Jun-04

Journal Publications

D.L. Moering, M.J. Madsen, B.B. Blinov and C. Monroe, "Experimental Measurement of Bell Inequality Violation Beteween an Atom and a Photon", Phys. Rev. Lett., p. , vol. , ( ). Submitted

L-. M. Duan, B.B. Blinov, D.L. Moehring, and C. Monroe, "Scalable Trapped Ion Quantum Computation with a Probabilisitic Ion-Photon Mapping", Quantum Inf. Comp., p. 165, vol. 4, (2004). Published

B.B. Blinov, D.L. Moehring, L-.M. Duan, and C. Monroe, "Observation of Entanglement between a single Trapped atom and a Single Photon", Nature, p. 153, vol. 428, (2004). Published

B. Sun, M. S. Chapman, and L. You, "Atom-photon entanglement generation and distribution
", Phys. Rev. A, p. 042316, vol. 69, (2004). Published

Books or Other One-time Publications

Web/Internet Site

URL(s):
http://iontrap.physics.lsa.umich.edu
Description:
This site maintains an extensive tutorial on ion trap physics as it relates to the ITR project, including interactive simulations of atomic ion motion and a map of the ?periodic table of laser-coolable ions? and their relevant energy levels.

Other Specific Products

Contributions

Contributions within Discipline:
The entanglement of a single atom and a single photon have great significance in the field of quantum information science. This system may be a critical linkage between stable quantum memories and reliable quantum communication channels. In considering this system, in collaboration with Prof. Luming Duan, we have discovered an alternative method for scalable quantum computing relying on this atom-photon coupling. The architecture revolves around known quantum repeater protocols. The controllable entanglement of atoms and photons may permit more reliable quantum communication tasks such as quantum cryptography or distributed quantum computing.

Contributions to Other Disciplines:
Our work in quantum information science has a broad impact on many areas of science and technology, both within several areas of physics (condensed matter, atomic, molecular and optical) as well as in mathematics and computer science. The field is intrinsically interdisciplinary and brings together ideas from many formally independent fields of research.

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: less than 20 percent of current funds

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Book

Any Product

Contributions: To Any Human Resource Development

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering

Major Findings

Under this project, quantum entanglement between a single atom and a single photon has been established for the first time. This result has recently appeared on the cover of Nature. In the experiment, a single trapped $^{111}Cd^{+}$ ion is initially excited to a state that has multiple decay channels, and a single photon is emitted as the ion decays. Along a certain emission direction selected by an aperture, the photonís polarization is entangled with particular hyperfine ground states in the de-excited atom. To verify the entanglement, we subsequently perform polarization analysis of the photon and state detection of the trapped ion. This system is reminiscent of the production of entangled photon pairs through spontaneous optical parametric down-conversion, but in the current system one of the two daughter qubits resides within a trapped atomic ion ñ perhaps the most reliable of all qubit memories. This is the first direct observation of entanglement between stationary and ì flyingî qubits, and is accomplished without employing cavity-QED techniques or a prepared nonclassical light source. This source of entanglement may be used for a variety of quantum communication protocols, and for seeding large-scale entangled states of trapped ion qubits for scalable quantum computing.